Chapter 6
Temperature Control of Mass Concrete

6-1. Introduction

Temperature control of mass concrete is necessary to prevent cracking caused by excessive tensile strains that result from differential cooling of the concrete. The concrete is heated by reaction of cement with water and can gain additional heat from exposure to the ambient conditions. Cracking can be controlled by methods that limit the peak temperature to a safe level, so the tensile strains developed as the concrete cools to equilibrium are less than the tensile strain capacity.

6-2. Thermal Properties of Concrete

a. General. The properties of concrete used in thermal studies for the design of gravity dams are thermal diffusivity, thermal conductivity, specific heat, coefficient of thermal expansion, heat of hydration of the cement, tensile strain capacity, and modulus of elasticity. The most significant factor affecting the thermal properties is the composition of the aggregates. The selection of suitable aggregates is based on other considerations, so little or no control can be exercised over the thermal properties of the aggregates. Type II cement with optional low heat of hydration limitation and a cement replacement are normally specified. Type IV low-heat cement has not been used in recent years, because in most cases heat development can be controlled by other measures and type IV cement is not generally available.

b. Thermal conductivity. The thermal conductivity of a material is the rate at which it transmits heat and is defined as the ratio of the flux of heat to the temperature gradient. Water content, density, and temperature significantly influence the thermal conductivity of a specific concrete. Typical values are 2.3, 1.7, and 1.2 British thermal units (Btu)/hour/foot/Fahrenheit degree (°F) for concrete with quartzite, limestone, and basalt aggregates, respectively.

c. Thermal diffusivity. Diffusivity is described as an index of the ease or difficulty with which concrete undergoes temperature change and, numerically, is the thermal conductivity divided by the product of specific heat and density. Typical diffusivity values for concrete range from 0.03 square foot/hour for basalt concrete to 0.06 square foot/hour for quartzite concrete.

d. Specific heat. Specific heat or heat capacity is the heat required to raise a unit weight of material 1 degree. Values for various types of concrete are about the same and vary from 0.22 to 0.25 Btu's/pound/°F.

e. Coefficient of thermal expansion. The coefficient of thermal expansion can be defined as the change in linear dimension per unit length divided by the temperature change expressed in millionths per °F. Basalt and limestone concretes have values from 3 to 5 millionths/°F; quartzite concretes range up to 8 millionths/°F.

f. Heat of hydration. The reaction of water with cement is exothermic and generates a considerable amount of heat over an extended period of time. Heats of hydration for various cements vary from 60 to 95 calories/gram at 7 days and 70 to 110 calories/gram at 28 days.

g. Tensile strain capacity. Design is based on maximum tensile strain. The modulus of rupture test (CRD-C 16) is done on concrete beams tested to failure under third-point loading. Tensile strain capacity is determined by dividing the modulus of rupture by the modulus of elasticity. Typical values range from 50 to 200 millions depending on loading rate and type of concrete.

h. Creep. Creep of concrete is deformation that occurs while concrete is under sustained stress. Specific creep is creep under unit stress. Specific creep of mass concrete is in the range of 1.4×10^{-6}/pounds per square inch (psi).

i. Modulus of elasticity. The instantaneous loading modulus of elasticity for mass concrete ranges from about 1.5 to 6×10^{6} psi and under sustained loading from about 0.5 to 4×10^{6} psi.

6-3. Thermal Studies

a. General. During the design of gravity dams, it is necessary to assess the possibility that strain induced by temperature changes in the concrete will not exceed the strain capacity of the concrete. Detailed design procedures for control of the generation of heat and volume changes to minimize cracking may be found in the *ACI Manual of Concrete Practice*, Section 207. The following concrete parameters should be determined by a division laboratory: heat of hydration (CRD-C 229), adiabatic temperature rise (CRD-C 38), thermal conductivity (CRD-C 44), thermal diffusivity (CRD-C 37), specific heat (CRD-C 124), coefficient of thermal expansion (CRD-C 397, 125, and 126), creep (CRD-C 54), and tensile strain capacity (CRD-C 71). Thermal properties testing should not be initiated until aggregate investigations have proceeded to the point that the most likely aggregate sources are determined and the availability of cementitious material is known.

b. Allowable peak temperature. The peak temperature for the interior mass concrete must be controlled to prevent cracking induced by surface contraction. The allowable peak temperature commonly used to prevent serious cracking in mass concrete structures is the mean annual ambient temperature plus the number of degrees Fahrenheit determined by dividing the tensile strain capacity by the coefficient of linear expansion. This assumes that the concrete will be subjected to 100-percent restraint against contraction. When the potential temperature rise of mass concrete is reduced to this level, the temperature drop that causes tensile strain and cracking is reduced to an acceptable level.

6-4. Temperature Control Methods

The temperature control methods available for consideration all have the basic objective of reducing increases in temperature due to heat of hydration, reducing thermal differentials within the structure, and reducing exposure to cold air at the concrete surfaces that would create cracking. The most common techniques are the control of lift thickness, time interval between lifts, maximum allowable placing temperature of the concrete, and surface insulation. Postcooling may be economical for large structures. Analysis should be made to determine the most economic method to restrict temperature increases and subsequent temperature drops to levels just safely below values that could cause undesirable cracking. For structures of limited complexity, such as conventionally shaped gravity dams, satisfactory results may be obtained by use of the design procedures in ACI 207 "Mass Concrete for Dams and Other Massive Structures." Roller compacted concrete thermal control options include the installation of contraction joints, winter construction, mixture design, and increased heat dissipation. Contraction joints can be created by inserting a series of cuts or metal plates into each lift to produce a continuous vertical joint. Using very high production and placement rates, RCC construction can be limited to colder winter months without excessive schedule delays. The normal lift height of 1 to 2 feet provides for an increased rate of heat dissipation during cool weather.